

Feasibility Study for Implementing Magnetic Suspension in the Glenn Research Center 225cm² Supersonic Wind Tunnel for Testing the Dynamic Stability of Blunt Bodies

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ABSTRACT

The implementation of a magnetic suspension system in the NASA Glenn Research Center (GRC) 225 cm² Supersonic Wind Tunnel would be a powerful test technique that could accurately determine the dynamic stability of blunt body entry vehicles with no sting interference. This paper explores initial design challenges to be evaluated before implementation, including defining the lowest possible operating dynamic pressure and corresponding model size, developing a compatible video analysis technique, and incorporating a retractable initial support sting.

1. Introduction

The dynamic stability of blunt bodies during planetary entry is difficult to quantify as computational methods have yet to demonstrate accurate predictive capabilities and experimental methods cannot explicitly measure damping derivatives. Ballistic range testing has been used in the past to determine dynamic behavior of blunt body vehicles by firing test models down a test range from a gun at low supersonic Mach numbers. Photographs are taken of this test model during flight to monitor the capsule's position and angle. Using these photos, a 6 degree of freedom simulation is fit to the data and the capsule aerodynamics are returned. Many issues, such as inconsistent initial conditions and the decommissioning of test ranges, has led to interest in implementing a magnetic suspension system in a wind tunnel for the dynamic stability testing of blunt body entry vehicles. In these proposed experiments, the magnetic system will react against aerodynamic and gravitational forces to hold the model in a fixed position in the wind tunnel and record the model's oscillations. High-speed cameras will capture the model's position and angle of attack over time and a trajectory will be fit to these data points, much like ballistic range testing.

2. Magnetic Suspension System

During tunnel operation, a blunt body model comprised of a non-magnetic material surrounding an iron spherical core, rather than a bar magnet, will be suspended in the test section. A bar magnet's geometric asymmetry allows an external magnetic field to impart a moment on the test model while an iron ball with spherical symmetry will see no moments from an external field. With this switch, only the field gradient will affect the test model's position in the tunnel and the oscillations it experiences will be completely aerodynamically driven. Past methods attempted to measure moments and aerodynamic forces from the behavior of the magnetic suspension system controller, however, for this proposed system high speed cameras will capture the path and orientation of the vehicle. The oscillations observed in the photographs will be analyzed with the same technique as used in ballistic range testing.

3. Facility

The NASA Glenn 225 cm² Supersonic Wind Tunnel was selected for this study because of its capability to run at low supersonic speeds which are of greatest concern for dynamic instability for blunt bodies during planetary entry. By interchanging nozzle blocks, Mach 2, 2.5, and 3 can be tested with the square 15cm test section. At Mach 2.5 the tunnel also has a compatible 17cm axisymmetric test section as shown in figure 1 below.

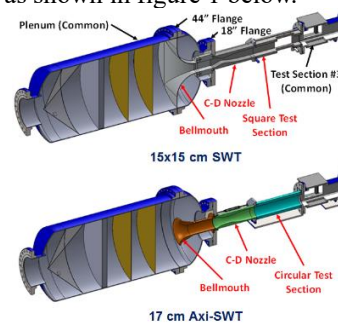


Figure 1: Rectangular and Axisymmetric Test Section Configuration.

4. Areas of Investigation

Model Blockage: It is critical to determine model sizes for given wind tunnel conditions so that the magnetic suspension and balance system can be sized accordingly. A smaller model is preferable for wind tunnel testing because it would reduce blockage concerns as well as resultant boundary layer and wall effects. A larger model, however, is desirable for the magnetic suspension and balance system because the magnetic force produced on a body in a field of given field strength is proportional to the volume of the body, while the aerodynamic forces are proportional to the body's projected area. Therefore, it is desirable to test the largest possible model size while maintaining stable flow conditions in the wind tunnel that are not compromised by wall effects.

To solve this problem, blockage tests in the 225 cm² wind tunnel are being run to determine the largest possible model size for three different geometries, blunt bodies with semi-vertex angles of 45, 60, and 70 degrees.

The percentage on the left hand column of Table 1 denotes fraction of the test section area the maximum model area comprises. Table 1 shows the results from Mach 2.5 testing using the 17 cm axisymmetric configuration.

Table 1: Results of Mach 2.5 Blockage Study,
S: Tunnel Start, U: Tunnel Did Not Start, NT: Not Tested

Model	45 Degree	60 Degree	70 Degree
4%	S	S	S 7.7/6.4 psia
5%	S	S	S 7.9/6.4 psia
6%	S 18.1/6.4 psia	S	S 25.3/6.5 psia
7%	U	NT	U
8%	NT	NT	U
9%	NT	NT	U
10%	U	U	U
11%	NT	NT	U
12%	NT	NT	U
13%	NT	NT	U
14%	U	U	U

A trend observed in the wind tunnel tests was that although the tunnel technically had supersonic flow in the test section, a shock train still remained in front of the model. The tunnel's total pressure was then increased further until the shock train passed behind the test model where it was then recorded as a successful data point. Many models were too big and the shock train remained in front despite the maximum total pressure of 40 psi being applied. The largest model size that allowed the shock to pass was the 6% model size for all geometries. Some models were not tested because models of a less blunt geometry like the 45 degree capsule would have an easier time starting than more blunt models, so if the 45 degree model wouldn't start for a particular size there was no need to test the rest. The first number listed in the table indicates the total pressure at which the shock train moves behind the model with increasing pressure while the second is the total pressure where the shock train came back in front when decreasing the total pressure. It should be noted that the second total pressure value is relatively similar value for all of the models.

In addition, the model's location will be altered in future tests to see how starting characteristics are affected by boundary layer thickness. The above data is for test models near the test section exit, but the tests will be repeated with the models near the nozzle exit where the boundary layer is thinner. The results will be compared and the necessary horizontal location of the model and the magnetic suspension system can be determined.

Shock-Wall Interaction: In supersonic flow, a bow shock forms ahead of the blunt body model. Depending on the size of the model and the proximity to the test section walls, the reflected shock could interfere with the wake behind the model. This condition is to be avoided since the dynamics of blunt bodies are wake-driven and interference from the test section walls would result in corrupted data. In order to address this, wind tunnel tests of the model fixed with different pitch angles will be run and a minimum distance will be determined for the magnetic controller.

Video Analysis: High speed cameras have been used for many wind tunnel tests, but both blunt bodies and magnetic suspension systems pose difficulties to this method of analysis. In this experiment, two orthogonal high-speed cameras will capture the change in position and angle of the suspended model. This system will be initially tested on a different lab-grade, subsonic 6x6inch vertical spin tunnel to validate the method. A camera support configuration must be designed and fabricated so that both cameras are positioned to capture the entire model trajectory, but close enough so that the image is clear enough to determine its position with accuracy. In addition, lighting options must be assessed since the model must be clearly illuminated in the tunnel for photographic clarity. The technique used to analyze the model's movement will also have to be chosen and refined. Past high-speed footage used marks inscribed on the model to determine the movement of the model through a computer software visual analysis technique. Another method is to illuminate the model against the backdrop of the test section using strobe lighting and observe changes in the model's shadow. This technique will be compared against data from a model with prescribed oscillations to determine the accuracy.

This potential set-up poses difficulty because the axisymmetric nature of a blunt body vehicle makes it difficult to determine the exact orientation of the vehicle. Furthermore, a potentially large magnetic suspension system could inhibit optical access. Because of this, potential mounting locations will have to be considered as well as a compact design.

Initial Support Sting: Current blockage tests have shown that the initial dynamic pressure to start the tunnel might be higher than the lowest operational dynamic pressure of interest here and exceed the capability of the magnetic suspension system. Because of this, a support sting could be used during tunnel start and removed as the pressure is lowered. If necessary, space for an easily retractable support sting will be designed with special focus on consistent initial conditions over multiple tests.

5. Conclusion

This project is important because a deep understanding of the behavior of capsules during entry is necessary for trajectory analysis as well as the safety of robotic or human missions. Magnetic suspension would allow for inexpensive testing of blunt body capsules so that dynamic aerodynamics coefficients can be determined to an improved or similar degree of accuracy as ballistic range testing. This project would serve to answer design questions that would be used to create a beneficial test technique in the GRC 225 cm² tunnel as well as open the door to impactful innovations in magnetic suspension.

References

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